A MARINE INVERTEBRATE FAUNULE FROM THE LINDAVISTA FORMATION, SAN DIEGO, CALIFORNIA

GEORGE L. KENNEDY

ABSTRACT.—A small mainly molluscan invertebrate fauna, dominated by the Pismo clam *Tivela stultorum* (Mawe), occurs in the reportedly unfossiliferous Lindavista Formation on the Linda Vista Terrace (at an altitude of 130-140 m) east of Murphy Canyon, city of San Diego, San Diego County, California. The faunule is suggestive of two habitats, an exposed open coast sandy beach, and a cobble or rocky-bottom, both at littoral or shallow adlittoral depths. The age of the Lindavista Formation may either be late Pliocene or early Pleistocene on the basis of the fauna, which contains the extinct species *Arca sisquocensis* Reinhart and *Pecten bellus* (Conrad). Because of the fewer tectonic-related events experienced by the Lindavista Formation than by the unconformably underlying late Pliocene sediments, the formation may actually be early Pleistocene in age.

The presence of late Pleistocene marine fossils from the San Diego area has been well documented by numerous authors (see references in Kern, 1971; also Ellis, *in* Ellis and Lee, 1919; Berry, 1922; Valentine and Meade, 1961; Moore, 1968; Kern, Stump, and Dowlen, 1971; Bishop and Bishop, 1972). Fossils from the older Pleistocene(?) Lindavista Formation (called the Sweitzer Formation by some authors) are unknown from the San Diego area, although Minch (1967: 1170) has reported finding "poorly preserved casts" at one locality in the Lindavista Formation in the Tijuana-Rosarito Beach area of northwesternmost Baja California, Mexico. In August, 1971, Richard C. Schwenkmeyer of San Diego Mesa College located an exposure of fossiliferous beach sand containing numerous fragments and a few complete single valves of the Pismo clam *Tivela stultorum* (Mawe) in a new housing development east of Murphy Canyon in San Diego (Fig. 1). Mr. Schwenkmeyer kindly brought this discovery to my attention, and the results of the ensuing investigation form the basis for this note.

THE LINDAVISTA FORMATION

The Lindavista Formation, named for exposures near the Lindavista railroad siding (Hanna, 1926: 218), consists of several meters of iron-red, moderately indurated dirty sand and pebble-cobble conglomerate. Along the eastward extent of the formation, the sandy facies interfingers with terrestrial gravels which are probably deltaic in origin. In addition, the formation is commonly characterized by pea-sized hematitic concretions on weathered surfaces (Hanna, 1926: pl. 23; Emery, 1950). The lithology at the fossil localities (see also Register of Localities) varies from a very modern-looking clean gray laminated beach sand to a fossiliferous conglomerate rich in heavy minerals (Fig. 2).

The Lindavista Formation blankets the Linda Vista Terrace, a broad and essentially planar, slightly westward sloping wave-cut surface extending from the present coastline nearly fifteen kilometers inland, where it terminates at the base of the foothills. Remnants of this formation are exposed on terraces from northernmost Baja California (Minch, 1967: 1157, 1170) to areas near Oceanside in San Diego County (Emery, 1950: 214, and pl. 29). The most prominent features of the Linda Vista Terrace are the three ancient beach ridges which approximately parallel the present coastline. These have been interpreted as stillstands during the marine regression which followed cutting of the terrace (Peterson, 1970: 122). Marine sediment along the eastern margin of this wave-cut surface was deposited earlier than that toward the coast.

The history of Pliocene and Pleistocene sedimentation of the San Diego coastal plain has been summarized by Hertlein and Grant (1944) and by Peterson (1970). Two possible sea level stands have been postulated for the events in the formation of the Linda Vista

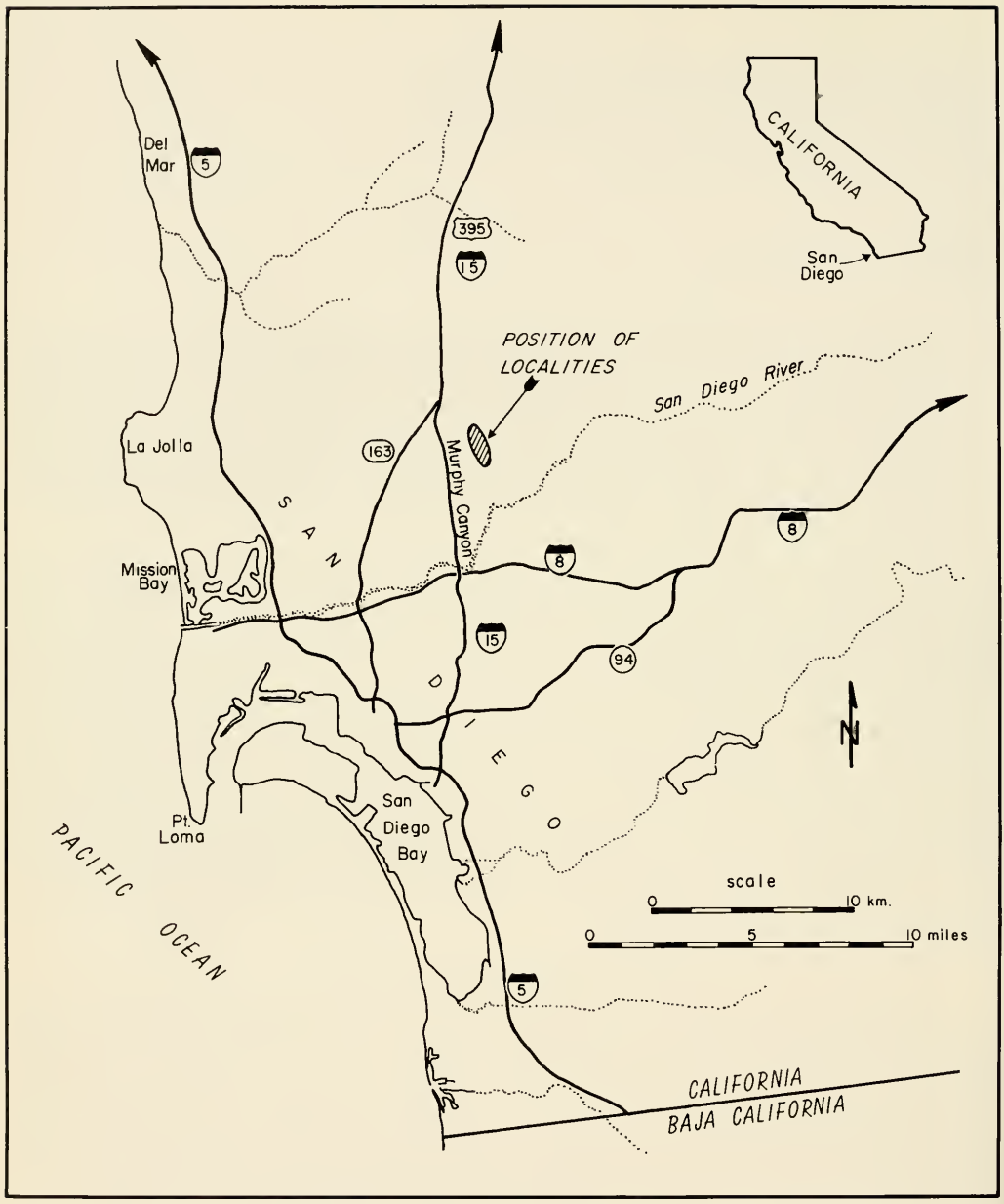

Figure 1. Index map of San Diego area showing general position of fossil localities on east side of Murphy Canyon.

Terrace (Hertlein and Grant, 1944: 64-65). One is that after deposition of the uppermost San Diego beds, the region was elevated but remained sufficiently below wave base for wave erosion or sea floor scour to truncate the marine Pliocene and Eocene beds. The Lindavista Formation therefore represents distribution by ocean waves and near-shore currents of coarse material derived from the local clastic formations, or by stream erosion on older rocks in the mountainous areas to the east. The second possibility is that parts of the San Diego Formation were elevated slightly above sea level at the close of the diastrophic movements which "inaugurated Sweitzer time." The soft nature of the San Diego beds resulted in their quick destruction by waves and subsequent reduction to a shallow submarine platform. However, formation of the Linda Vista Terrace may also have been the result of a relative subsidence of the coastal plain (or rise in sea level) with con-

comitant transgression of a shallow sea, then followed by submarine erosion. Subsequent retreat of the sea (as evidenced by the beach ridges) and deposition of the offlap facies (deltaic and terrestrial clastic sediments) to the east culminated deposition of the terrace material.

Despite problems of reconstructing these earlier events, at least 150 meters of relative sea-level change and only minor deformation has occurred during and since the creation of the Linda Vista platform (Peterson, 1970: 122). West of the Rose Canyon Fault considerable tilting and uplift has occurred, although not to the extent as affects the late Pliocene San Diego Formation underlying it (Moore, 1972: 116, fig. 3 [Structure contours on the base of the Lindavista Formation]). The Lindavista Formation to the south on San Diego Mesa is flat-lying and in slight angular unconformity with the underlying San Diego Formation which dips 6° to 8° to the south-southwest (Hertlein and Grant, 1944: 63 [as the Sweitzer Formation]).

AGE OF THE LINDAVISTA FORMATION

The age of the Lindavista Formation has been variously interpreted as late Pliocene to late Pleistocene. Originally Hanna (1926: 218) simply assigned his "Lindavista terrace material" to the Quaternary. Hertlein and Grant (1939: 71) considered their Sweitzer Formation (which equals the Lindavista Formation) to be younger than the Pliocene San Diego Formation and to be either late Pliocene or early Pleistocene in age. Milow and Ennis (1961: 28) called the "Lindavista Formation" upper Pleistocene, but they were referring instead to deposits of topographically lower and younger terraces than the Linda Vista Terrace. Their combined Sweitzer Formation and an overlying unnamed Sandstone comprise the Lindavista Formation of current usage. Most recently Peterson (1970: 122) has assigned the Lindavista Formation to the middle Pleistocene because of its medial position between the "Early Pleistocene?" higher greatly dissected Poway Terrace and the late Pleistocene lower terrace associated with the Bay Point Formation. Fossils collected from the Linda Vista Terrace (see below; also Fig. 3) indicate either a late Pliocene or early Pleistocene age for the formation. Because of the greater number of tectonic-related events experienced by the late Pliocene San Diego Formation (see above), the Lindavista Formation may actually be early Pleistocene in age, although further evidence is needed before any age determination can be substantiated.

FAUNA OF THE LINDAVISTA FORMATION

The fauna of the Lindavista Formation is essentially a modern one, with a few exceptions. Two of these, *Arca sisquocensis* Reinhart and *Pecten bellus* (Conrad), are known only from Pliocene and lower Pleistocene strata in California. *Turritella gonostoma hemphilli* Merriam, only questionably found in the Lindavista Formation, also occurs in upper Pliocene rocks in California. *Tegula hemphilli* Oldroyd occurs in both the upper Pliocene San Diego Formation, and the upper Pleistocene of Pacific Beach, San Diego. The remaining molluscan species are all extant, but range back into the Pliocene. The barnacle *Balanus pacificus* Pilsbry, also only doubtfully identified, is not positively known to occur in Pliocene or older rocks (Zullo, 1969: 10). These fossils indicate either a late Pliocene or early Pleistocene age for the fauna.

The possibility that the fossils have been reworked from the Pliocene San Diego Formation is slight, but cannot be discounted entirely. The Lindavista Formation in the vicinity of the fossil exposures unconformably overlies the Eocene Friars Formation and Stadium Conglomerate (Kennedy and Moore, 1971). Field investigations have revealed no outcrops of the San Diego Formation anywhere in the area (G. W. Moore, pers. commun.; Hertlein and Grant, 1944: 50). The closest exposures of Pliocene strata are all several kilometers distant, to the south on the south side of Mission Valley, and to the west in the vicinity of Mission Bay and on Mt. Soledad.

The following species were found in exposures of the Lindavista Formation on the east side of Murphy Canyon in San Diego. Nearly all the species are from one locality (SDSNH loc. 0325); numbers following the species name are the number of specimens (fragments in parentheses) collected from this locality, unless otherwise noted. For local-

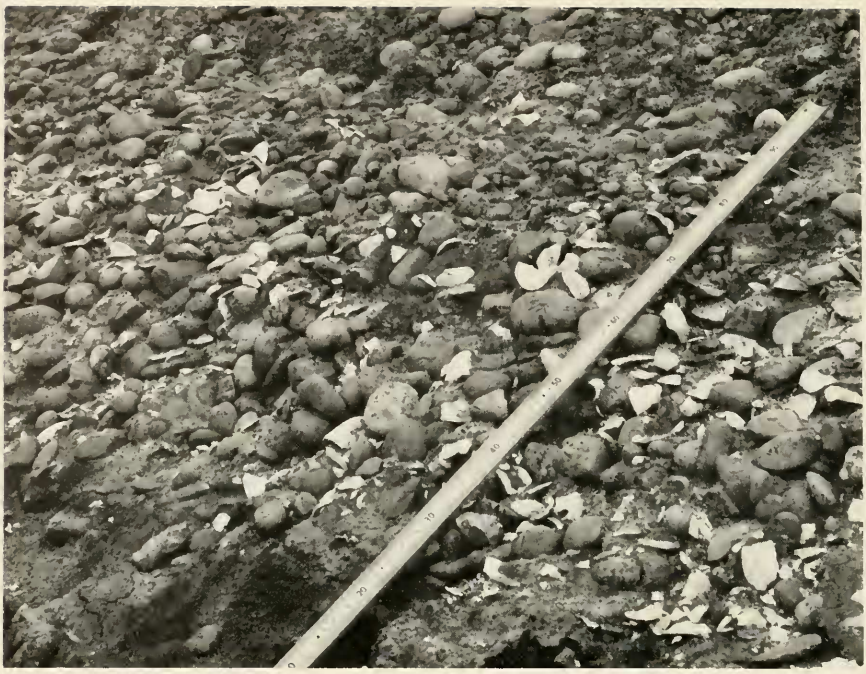

Figure 2. SDSNH locality 0329: Fossiliferous exposure on Santo Road, San Diego, showing heavy-mineral sand, cobble conglomerate, and fragmented valves of *Tivela stultorum*. Meterstick for scale.

ity data see Register of Localities.

Mollusca, Gastropoda: *Diodora arnoldi* McLean, 1966–3; *Calliostoma spp.*–(11); *Tegula hemphilli* Oldroyd, 1921–3(4); *Tegula funebralis* (Adams, 1855)–2(6); *Turritella* sp. cf. *T. gonostoma hemphilli* Merriam, 1941–(6); *Turritella* sp.–1(1); *Crepidula* spp.–(2); *Crucibulum spinosum*? (Sowerby, 1824)–(1); *Polinices recluzianus* (Deshayes, 1839)–1(?12); *Acanthina spirata* (Blainville, 1832)–(21); unidentified fragments–(3). Mollusca, Bivalvia: *Yoldia cooperi* Gabb, 1865–(1); *Arca sisquocensis* Reinhart, 1937–(1); *Ostrea* sp.–(1); *Pecten bellus* (Conrad, 1857)–1; "*Pecten*" spp.–(16); *Anomia*? sp.–1; *Pododesmus* sp.– (2); *Cardita* sp. aff. *C. affinis* Sowerby, 1833–1 at loc. 0329; *Lucinisca nuttalli* (Conrad, 1837)–2(15); *Tivela stultorum* (Mawe, 1823)–12, 1(15) at loc. 0321, (6) at loc. 0322, fragments not collected at locs. 0323 and 0324, (1) at loc. 0326, 3(10) at loc. 0329; *Protothaca*? sp.–(1) at loc. 0329; *Petricola carditoides* (Conrad, 1837)–(1); *Spisula hemphilli* (Dall, 1894)–(2); *Tellina*? sp.–(2); *Macoma nasuta*? (Conrad, 1837)–(1); *Zirfaea pilsbryi* Lowe, 1931–(6, ?2); *Penitella* sp.–(?1), (4) at loc. 0326; unidentified fragments–(9). Annelida, Polychaeta: spionid worm burrows–15 [in single *Tegula funebralis*]. Echinodermata, Echinoidea: echinoid spines–8. Arthropoda, Crustacea (Cirripedia): *Balanus* sp. cf. *B. pacificus* Pilsbry, 1916–1; *Megabalanus* sp.–2; unidentified barnacle wall plates–75 +.

PALEOECOLOGY

The fauna collected does not represent the remains of any single biotic community, but rather is a detrital death assemblage from several near shore marine habitats. Specimens have been derived mainly from two habitats: sandy beach and cobble or rocky-bottom.

An exposed open coast sandy beach habitat at littoral or adlittoral depths is strongly suggested by the great abundance of the Pismo clam *Tivela stultorum*, as well as by the presence of *Spisula hemphilli*. *Donax gouldi*, a common member of this habitat group was unexpectedly absent. Many specimens are quite fragmented (most post depositionally), but their association with the cobble conglomerate indicates either local transport before deposition, or mixing with an offlap regressive facies.

A cobble or rocky-bottom habitat is suggested by many of the species in the fauna, including those in the genera *Diodora, Calliostoma, Tegula, Acanthina, Arca, Cardita, Protothaca, Petricola, Penitella, Balanus,* and *Megabalanus*. Most of the specimens are fragmentary and while the conglomeratic nature of the outcrop may have been similar to the paleosubstrate (see above), mixing and local transport are indicated here.

In addition to the above habitats, there are representatives of soft-bottom (sand and mud) habitats which could have occurred in shallow protected bays or offshore below the level of effective wave action. These include species of *Turritella, Polinices, Yoldia, Pecten, Lucinisca, Tellina, Macoma,* and *Zirfaea.*

Most species are largely represented by only a relatively few fragments, and indicate at least local transport and mixing. The high degree of breakage may well be a consequence of the conglomeratic substrate and proximity to surf action.

Of the extant species represented in the fauna, only *Cardita* sp. aff. *C. affinis* does not occur today in the vicinity of San Diego. *Cardita affinis* occurs from Bahía de Pequeña (26° 12′ N) on the outer coast of southern Baja California, throughout the Gulf of California, and south to northern Peru. *Turritella* sp. cf. *T. gonostoma hemphilli*, a relative of the living *T. gonostoma s.s.*, which occurs today from the Gulf of California southward to Ecuador, also suggests warmer water. The remainder of the fauna suggests a water temperature comparable with that of the present Californian Province. There are no cold-water or strictly northern species in the fauna. The occurrence in Pleistocene sediments of both cooler water (Californian) and warmer water (Panamic) species cannot yet be satisfactorily explained.

Reconnaissance geology of the area of outcrop by George W. Moore (pers. comm.) indicates that the Lindavista Formation lies on the Eocene Friars Formation (soft sandstone) directly north of the eroded edge of the overlying Eocene Stadium Conglomerate, the contact between the two Eocene formations trending northeasterly. A ridge of the more resistant southward dipping conglomerate seems to have stood slightly in relief during erosion of the wave-cut platform. The fossiliferous deposits of the Lindavista Formation lie in an embayment etched into the poorly cemented Friars Formation directly north of a Pleistocene rocky headland of Stadium Conglomerate. This physiographic configuration may have been responsible for the accumulation of different habitat forms in the fauna. Subsequent deposition of an offlap facies (conglomerate and tight deltaic sandy claystone, never deposited to the west), protected the deposits from weathering and erosion which probably accounts for the general lack of fossils in the formation as a whole.

SYSTEMATIC NOTES

Mollusca: Gastropoda

Diodora arnoldi McLean, 1966

Fig. 3c

Range.—Crescent City, Del Norte County, California, to Isla San Martín, Baja California (McLean, 1966:6).

Remarks.—This small keyhole limpet occurs exclusively in the sublittoral zone and is not uncommon on the undersides of rocks below a depth of 9 m (McLean, 1969: 13). *Diodora arnoldi* is also known from the upper Pliocene San Diego Formation from southwesternmost San Diego County (LACMIP loc. 305A).

Tegula hemphilli Oldroyd, 1921

Fig. 3 a,b

Remarks.—This extinct low spired *Tegula* was described from upper Pleistocene deposits on the La Jolla Terrace at Pacific Beach, San Diego (Oldroyd, 1921: 115). It is also known to occur in the upper Pliocene San Diego Formation, where it is exposed on Telegraph Canyon Road, east of the city of Chula Vista.

Tegula funebralis (Adams, 1855)

Fig. 3d

Range.—Vancouver Island, British Columbia, to central Baja California (McLean, 1969: 22).

Remarks.—This species occurs strictly intertidally and is abundant in rocky areas at

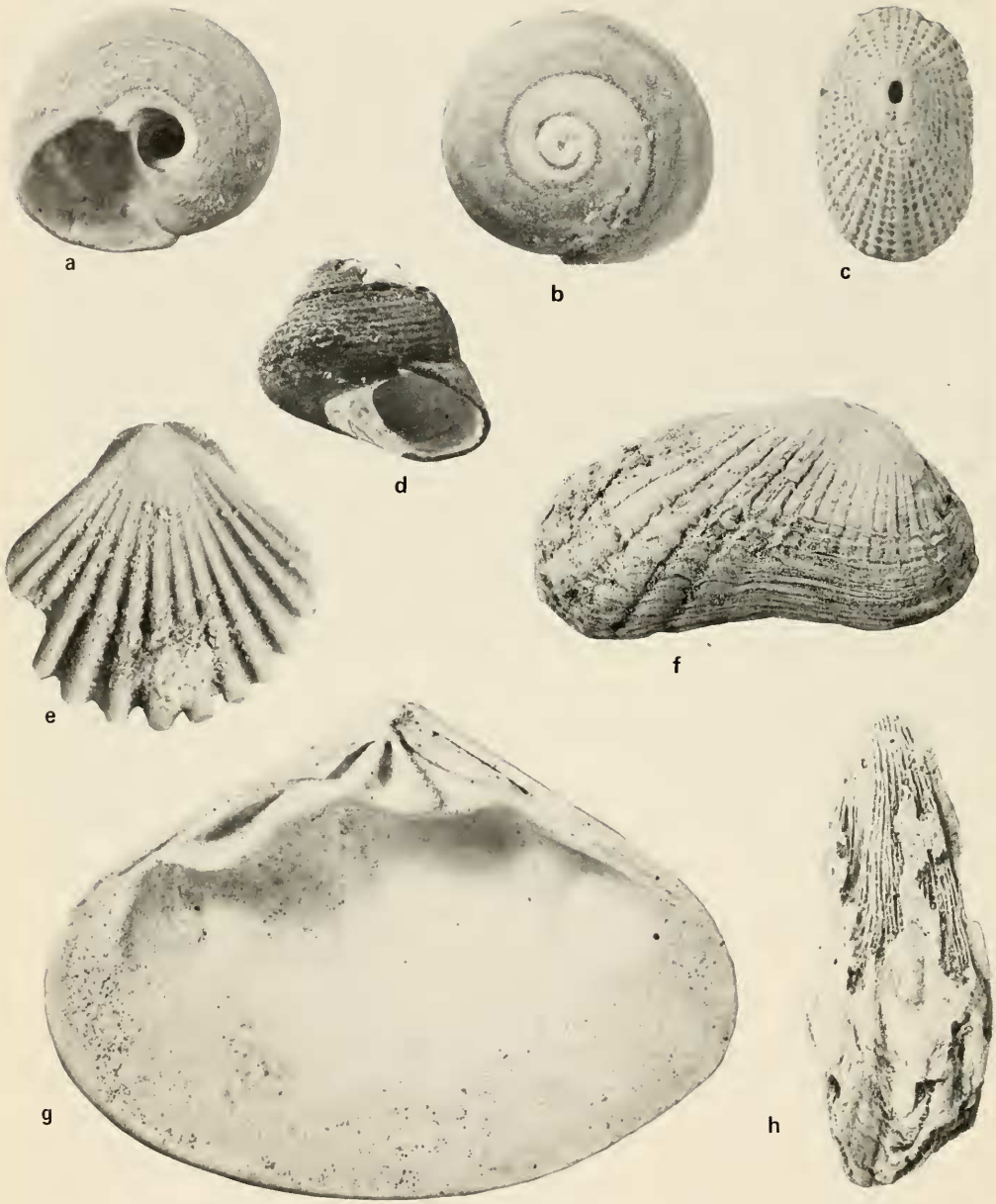

Figure 3. Fossils from the Lindavista Formation. a, b, *Tegula hemphilli*, SDSNH 15581, width 16.2 mm; c, *Diodora arnoldi*, SDSNH 14886, length 9.1 mm; d, *Tegula funebralis*, SDSNH 14889, width 27.2 mm; e, *Pecten bellus*, SDSNH 13117, height 22 mm; f, *Cardita* sp. aff. *C. affinis*, SDSNH 16678, length 59 mm; g, *Tivela stultorum*, SDSNH 14887, length 78.7 mm; h, *Megabalanus* sp., SDSNH 14888, height 60 mm.

the midtide level (McLean, 1969: 22). Dead shells are retained in the intertidal zone by hermit crabs, which use them for their own protection. The columella of one specimen has been extensively bored by spionid worms.

Mollusca: Bivalvia

Arca sisquocensis Reinhart, 1937

Remarks.—One fragment of this distinctive Pliocene and lower Pleistocene *Arca* was found. This species, described from the Pliocene Careaga Formation, also occurs in the lower Pleistocene Santa Barbara Formation (Reinhart, 1943: 25), as well as in the upper

Pliocene San Diego Formation exposed in southwesternmost San Diego County (LACMIP locs. 305 and 305A).

Pecten bellus (Conrad, 1857)

Fig. 3e

Remarks.—One small flat left valve referable to *Pecten bellus* has the apical angle, number of ribs, and muscle scar typical of the species. This characteristic middle to late Pliocene species also occurs in the lower Pleistocene Santa Barbara Formation (J. W. Valentine, pers. commun.). Sixteen additional pectinid fragments remain unidentified.

Cardita sp. aff. *C. affinis* Sowerby, 1833

Fig. 3f

Range.—[of *C. affinis*] Bahía de Pequeña, and the Gulf of California south to northern Peru (Keen, 1958: 85; Olsson, 1961: 190).

Remarks.—One complete right valve differs from Recent specimens examined by its more central umbo, rounded anterior and posterior margins, and greater thickness, although these differences may only be phenotypic. *Cardita affinis* occurs under rocks or in crevices intertidally and offshore to a depth of 27 meters (Keen, 1971: 107). This is the only living species in the fauna of the Lindavista Formation that does not presently occur along the San Diego coastline.

Fossil occurrences of *C. affinis* are known only from the upper Pliocene and Pleistocene of the southern part of the Gulf of California (Durham, 1950: 72; Hertlein, 1957: 62; Emerson and Hertlein, 1964: 341).

Tivela stultorum (Mawe, 1823)

Fig. 3g

Range.—Halfmoon Bay, San Mateo County, California, to Bahía Magdalena, Baja California (Fitch, 1953: 60).

Remarks.—This is the most abundant of any species found, and fragments and occasional complete valves were present at every locality in the area which produced fossils. No paired valves were found, and all appear to be detrital. A few specimens still exhibit faint coloration patterns. Many of the valves have been post-depositionally fragmented. *Tivela stultorum* usually occurs in the intertidal zone on flat sandy beaches on the open coast (exposed to the full force of the surf), or in channels leading into bays and estuaries (Fitch, 1953: 60).

Penitella sp. indet.

Remarks.—Several small specimens of a poorly preserved *Penitella* were removed from sandstone cobbles at two localities. The umbonal regions of all the specimens are too damaged for specific identification. Species of *Penitella* are commonly found in cobbles in molluscan death assemblages, and usually represent intertidal or high inner sublittoral zones on the open coast where wave action is strong and fine sedimentation does not occlude the siphonal openings.

Arthropoda: Crustacea

Cirripedia

Remarks.—Over 75 fragments of barnacle wall plates were found at one locality. These, although mostly unidentified, represent several species belonging to both *Balanus s.s.* and *Megabalanus* (Fig. 3h). Numerous fragments were recovered from the conglomeratic sandstone, but none were found attached to cobbles, nor were any bases found on any of the cobbles. A single opercular plate has been tentatively identified as *Balanus* sp. cf. *B. pacificus* Pilsbry, a species not positively known from Pliocene or older rocks (Zullo, 1969: 10). *Balanus pacificus* occurs today from San Francisco, California, to north-

ern Peru, and is common in Pleistocene deposits of California and northern Baja California (Zullo, 1969: 10).

REGISTER OF LOCALITIES

All of the following localities are from the lower Pleistocene (?) Lindavista Formation from exposures on the Linda Vista Terrace east of Murphy Canyon in the city of San Diego, San Diego County, California. Most of the specimens were collected by me in September (locs. 0321-0326) and late November (loc. 0329), 1971. These localities are now mostly on private residential property. Specimens have been deposited in the Department of Invertebrate Paleontology in the San Diego Natural History Museum and bear its locality numbers.

Loc. 0321. Northwest trending bank facing southwest on east (back) side of residence at 5349 Jazmin Court, San Diego. Unconsolidated sand. Altitude 142 m. Approximate coordinates: 32° 49.7′ N., 117° 5.6′ W. Locality found by R. C. Schwenkmeyer.

Loc. 0322. West-facing bank at the northeast corner of the intersection of Sandia Place and Gabacho Drive (10810 Gabacho Drive), San Diego. Fossil fragments in gray laminated and cross-bedded non-indurated beach sand with occasional scattered pebbles. Approximate coordinates: 32° 49.8′ N., 117° 5.8′ W.

Loc. 0323. North-facing bank on south side of lot at 10805 Gabacho Drive (in cul-de-sac opposite Sandia Place), San Diego. Laminated gray unconsolidated beach sand overlain by well-indurated fossiliferous conglomeratic sandstone, which in turn is overlain by a terrestrial conglomeratic facies. Approximate coordinates: 32° 49.8′ N., 117° 5.8′ W.

Loc. 0324. East-west trending utilities ditch in south side of street along north side of 10825 Gabacho Drive, San Diego. Approximate coordinates: 32° 49.8′ N., 117° 5.8′ W.

Loc. 0325. North-facing bank on south side of residence at 10735 Montego Drive (in southeast corner of first cul-de-sac on Montego Drive west of El Noche Way), San Diego. Unconsolidated fossiliferous conglomeratic sandstone. Altitude 131 m. Approximate coordinates: 32° 49.7′ N., 117° 5.8′ W. Locality found by G. W. Moore.

Loc. 0326. West-facing bank on east side of residence at 10735 Montego Drive (in southeast corner of first cul-de-sac on Montego Drive west of El Noche Way), San Diego. Approximate coordinates: 32° 49.7′ N., 117° 5.8′ W.

Loc. 0329. Ninety-meter stretch along west-facing roadcut on east side of Santo Road, beginning approximately 35-40 meters north of intersection of Santo Road and Monte Negro Drive, San Diego. Fossiliferous lenses mixed with black heavy-mineral sand and cobble conglomerate. Locality found by G. W. Moore.

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